

Green House Gas Emissions

Evaluating the Reduction in Green House Gas Emissions Achieved by the Implementation of the Household Appliance Recycling in Japan*

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Abstract

Background, Aim and Scope. The Home Appliance Recycling Law (hereunder referred to as the Law) for used cathode ray tube (CRT) TVs, air conditioners, refrigerators and washing machines was enacted in April 2001 in Japan. The Law requires that retailers reclaim, and manufacturers and importers recycle such home appliances. Consumers are required to pay collection and recycling fees incurred in disposing of any of the four home appliances. Home appliances must, as a general rule, be managed in accordance with the Law. In reality, other routes exist, such as via local authorities, scrap processors, illegal dumping and exporting. At about the time the Law was enacted, the refrigerant used for air conditioners and refrigerators was replaced by more environmentally friendly substances such as isobutene. Local authorities had the responsibility of disposing of the appliances of households before the enactment of the Law. It was general practice for local authorities to dispose of home appliances in landfills after breaking them up and recovering valuable resources such as iron, copper and aluminum. Although they made efforts to recover refrigerant fluorocarbons, there were not required to do so.

Materials and Methods. This study analyzed the material flow resulting from the Law and other processing flows to quantify the global warming effect caused by home appliance recycling using the life cycle assessment (LCA) method. To evaluate the Law and to develop policy planning, the challenges of future efforts will be considered using time series data. For these reasons, we have assessed the Project Scenario, which corresponded to the present reality; the Baseline Scenario, which assumed that measures such as the Law were not implemented after 2000, and the Ideal Scenario, where all used products were recycled as prescribed by the Law. The environmental impacts for each scenario were estimated using value, which was obtained from multiplying the amount of reproduction and waste treatment by each inventory data.

Results. It is estimated that emission reductions of 4.7E+4 t CO₂e, subtracted the Project Scenario from the Baseline Scenario, were reduced for TVs in 2001 through recycling. The impact from recycling glass from cathode ray tube (CRT) televisions is significant. An improvement of 2.3E+4 t CO₂e could be anticipated by upgrading to the Ideal Scenario in 2001.

It was estimated that there was a reduction of 9.2E+5 t CO₂e in 2001 for air conditioners. Although the effect of the recovery for

refrigerants contributed greatly, some fluorocarbons that are still discharged have had a considerable impact on greenhouse gas emissions. Hypothetically, a reduction of 3.2E+6 t CO₂e could be anticipated with the Ideal Scenario in 2001.

A reduction of 2.6E+6 t CO₂e was achieved for refrigerators in 2001. Although a further reduction can be anticipated through the Ideal Scenario, there will not be much difference with the Project Scenario by 2010.

It was estimated that 3.8E+4 t CO₂e were reduced for washing machines in 2001. Only a small improvement can be expected through the Ideal Scenario.

Discussion. Since many assumptions were used in this study, a sensitivity analysis was carried out in order to grasp their impact. The findings of the sensitivity analysis are that the uncertainties are large, but the number of the greenhouse gas (GHG) reductions is still clear except for the difference between the Project Scenario and the Ideal Scenario for TVs. This analysis gives authenticity to the findings.

Conclusions. Establishing a system for liquid crystal display and plasma display panel TVs is desirable because the absolute amount of used LCD/PDP TVs will rapidly increase as the usage of CRT TVs rapidly decreases from 2007.

With regard to refrigerant recovery from air conditioners, a significant decrease in GHG emissions has been recorded. There is, however, still ample room for improvement. It will be necessary to switch to refrigerants with low global warming potentials (GWPs) or work more on improving the recovery rate in the future. Alternatives and recovery of fluorocarbons from refrigerators contributed greatly to GHG reductions. The GHG emissions from refrigerator recycling will be minimal whether used refrigerator will be processed legally or not because most used refrigerators will contain natural refrigerants in the near future. The improvement for washing machines was low because it was assumed that their main constituent steel has been previously recycled, and that the plastic recycling rate will not change significantly in the future. An improvement in the recycling technology itself is required. This study was carried out on four home appliance products, and it was found that the Home Appliance Recycling Law has brought significant reductions in GHG emissions. There is also room to make GHG reductions through improving the processing methods further.

Recommendations and Perspectives. The impact on GHG emissions by fluorocarbons of air conditioners and refrigerators is the greatest. Adequate measures are particularly required for air conditioners that may continue to discharge GHGs in the future.

Keywords: Air conditioner; green house gases; home appliance; LCA(Life Cycle Assessment); policy evaluation; policy planning; recycling, refrigerator; televisions; time series data; washing machine

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Introduction

The Home Appliance Recycling Law (hereunder referred to as the Law) for used CRT (Cathode-Ray Tube)-based TVs, air conditioners, refrigerators and washing machines was enacted in April 2001 in Japan (Fig. 1).

The Law required retailers to reclaim used home appliances, and for manufacturers and importers to recycle such goods, and consumers to pay collection and recycling fees incurred in disposing of any of the four home appliances. The recycling fee differs by manufacturer and the type of home appliance, but the fee set out by the manufacturers is between ¥2,520 and ¥5,870. As a ratio of the disposed home appliances reclaimed, manufacturers and importers must recycle 55 percent of TVs, 60 percent of air conditioners, 50 percent of refrigerators and over 50 percent of washing machines. They must also collect refrigerants and foaming agents of fluorocarbons used for insulation.

The manifesto system has been established to ensure that specified home appliances are appropriately handled from the consumers to retailers and manufacturers in the recycling process. The system even allows consumers to check if the waste is being recycled responsibly. The government's role is to correct and advise those companies that provide information on recycling, and to penalize those that do not follow the law properly. Manufacturers are implementing non-fluorocarbons and improvements on disassembly as an activity of 'Design for Environment' in order to achieve a reduction in disposal costs.

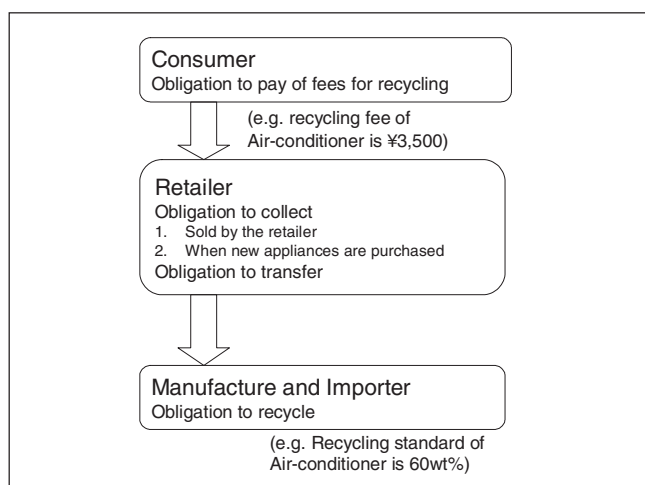


Fig. 1: Scheme of the household appliance recycling law

1 Background

Home appliance manufacturers are divided into two groups, A and B, in relation to recycling used products. Group A consists of Toshiba, Matsushita, JVC, and 18 other companies. This group has adapted to the Law in partnership with traditional scrap processors. Group B consists of Sharp, Sony, Mitsubishi Electric, and 20 other companies. This group has met the requirements of the Law by investing in large-scale new facilities. As of March 2005, groups A and B had recycling plants in 44 locations in Japan.

As stated, used home appliances must, as a general rule, be managed in accordance with the Law. However, in reality, other material management routes exist, including via local authorities, scrap processors, illegal dumping and exporting. The partnership established by Osaka Prefecture in May 2003 with industrial waste disposal companies is a typical example of the local authority route. The statutory recycling standard and fluorocarbons recovery are implemented via this route. With the scrap processor alternative, the used products are collected and disposed of by waste disposal companies under the Waste Management and Public Cleansing Law, unlike the route mentioned above. Although they also must meet the standard of the recycling, the details of material flow are not clear. Only valuable resources such as iron, copper and aluminum may be recovered via this route. With the illegal dumping route, waste is dumped in mountains and forests to avoid paying the recycling fee. As illegal dumping not only ruins the landscape, but also carries the risk of hazardous substances permeating into the local environment, the dumped waste is recovered by local authorities when it is discovered. With the exporting route, the appliance or the parts are reused in other countries.

In FY2004, a total of 1.1E+7 units and 4.3E+5 metric tonnes were collected because of the Law, and over 3.1E+5 tonnes were recovered as valuable resources [1]. On the other hand, there are discrepancies of quantity between 2.2E+7 units that was statistically estimated by Tasaki et al. 2001 [2] and the 1.1E+7 units actually collected units under the Law. This gap is believed to be due to exports abroad, disposal by local authorities and disposal outside the framework of the Law by scrap processors. Some of these disposal methods do not recover fluorocarbons properly. At about the time the Law was enacted, the refrigerant for air conditioners and refrigerators was replaced by more environmentally friendly substances, such as isobutane.

Local authorities had the responsibility of disposing of home appliances of general households before the enactment of the Law. It was general practice for local authorities to dispose of home appliances in landfills after breaking them up and recovering valuable resources such as iron, copper and aluminum. Although they made efforts to recover refrigerant fluorocarbons, they were not required to do so. However, since many local authorities collected home appliances free of charge, there was less illegal dumping.

2 Goal and Scope Definition

It is required to quantify the effect of the recycling activities. Yoshida et al. 2000 has assessed the effects of used home appliance disposal in accordance with the Law, which indicated that the impact on global warming was significantly reduced compared to landfilling the waste or disposal through the traditional shredder disposal method [3]. Matsuto et al. 2004 clarified the detailed material composition of parts recovered from one plant, and also the material balance, including heavy metals, resulting from recycling activities [4]. However, since these studies assess the

effects of recycling activities for a single home appliance item, the whole material flow has not been taken into consideration. Hara et al. 2001 calculated the energy consumption of refrigerators in Japan [5], and Matsuno et al. calculated the changes in the environmental burden of the air conditioners from 1990 to 2010 in Japan by taking into account refrigerant changes using the Population Balance Model [6]. Kondo and Nakamura 2004 analyzed the knock-on effect on the whole industry quantitatively, and indicated the effect of recycling, the design for disassembly and the extension of products lifetime in terms of CO₂ emissions and land-fill disposal volume using the Input-Output table [7]. However, these have not assessed the impact of illegal dumping, the effect of changes in materials used or all other home appliances [6–7].

As stated above, there have been many studies on used home appliances, but they are insufficient for assessing the global warming impact of the Law. This study analyzed the material flow that resulted from the Law and other processing flows to quantify the global warming impact caused by home appliance recycling using the LCA method. To evaluate the Law and to assist with policy planning in the future, time series data will be utilized. For these reasons, we have assessed three scenarios: the Project Scenario, which corresponds to reality; the Baseline Scenario, which assumes that measures such as the Law were not implemented; and the Ideal Scenario, where all used products are recycled under the Law.

3 Implementation Method

The purpose of this study was to analyze the effects of various efforts related to home appliance recycling from the viewpoint of global warming mitigation. As such, the study did not focus on the manufacture or use of home appliances, but assessed the dismantling and processing of recycled materials and the appropriate disposal of the residue. Fig. 2 shows the system boundary of the study. Dismantling, reproduction and waste treatment process are assessed in sub-system boundary A. With the notion that the environmental burden is reduced in other product systems by recovering the materials, the process involved in equivalent materials manufacturing was established as sub-system boundary B, and the environmental burden was assessed in terms of negative impacts. The environmental impacts for each scenario

were estimated using value, which was obtained from multiplying the amount of reproduction and waste treatment by each inventory data. Regarding the functional unit, it was defined as the processing of each used product disposed of in Japan annually. The focus of the study was greenhouse gas emissions; therefore, CO₂, CH₄, N₂O, and fluorocarbons emissions were estimated. The IPCC GWPs index from 2001, 100 years index, was used for determining the impact of the emissions on global warming. The following is the assessment method based on the implementation procedures for the analysis.

3.1 Basic data collection experiment

In order to collect basic data, used home appliances were disposed of in batches of 20. The recycling method was assumed to be the Line Dismantling Method, which will be discussed later. The weight of each part and the amount of ferrous and non-ferrous scraps recovered from the shreds were measured. Regarding the material balance of other recycling methods such as the Manual Dismantling Method, the mass of parts removed in the manual dismantling process was recorded [8].

3.2 Calculation of home appliance discharge volume by year

The number of used home appliance units discharged per manufacturing year from 1990 to 2010 in Japan has been calculated using the method of Tasaki et al. 2001 [2]. The latest product shipping volume of 2005 was updated in the statistics [9,10]. Furthermore, sales of Liquid Crystal Device (LCD) and Plasma Display Panel (PDP) TVs, which are exempt from the Law, have been rapidly increasing in recent years. The share of LCD/PDP TVs was extrapolated by approximation formula (Eq. 1). The formula was developed by applying the ratio of LCD/PDP TVs up to 2005 in the statistics [10], and assuming that the share would rapidly increase after 2006 and reach 100 percent by 2015.

$$y = 0.995 / \{1 + 37.894 \exp(-0.810x)\} \quad (1)$$

Where:

x is the number of years from the base year 1999

y is the LCD/PDP TV composition ratio

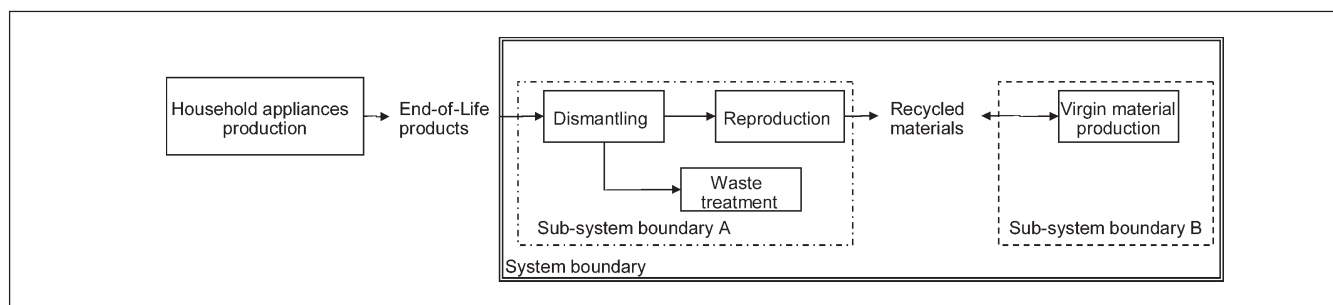


Fig. 2: System boundary

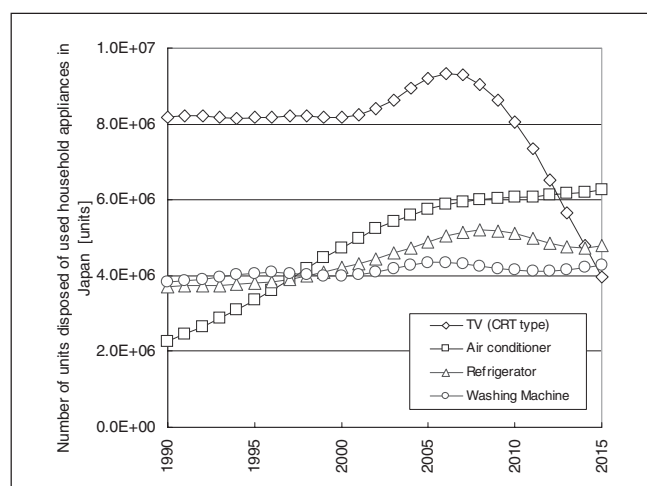


Fig. 3: Number of end of life household appliances in Japan

The estimated value of the discharge volume of used home appliances is indicated in Fig. 3. In 2010, the total number of home appliances used is expected to increase by 30% from 1990, due in large part to an increase in the number of used air conditioners.

3.3 Establishing the material composition and weight by year

The weight and material composition of home appliances are changing annually due to changes in technology, market demand, and regulation. The wooden cabinet and back cover of TVs have been replaced by plastic. This has made the TVs lighter, and increased the proportion of glass in TV construction. The material of the main body of refrigerators has been changed from steel to plastic. Although there have been changes to air conditioners and washing machines in terms of individual parts, there have been no significant changes as a whole. In this study, the material composition for each period was established as seen in Table 1 according to a literature survey [11–14]. The weights were assumed to be the same in all periods based on the results of home appliance recovery, with TVs at 27 kg, air conditioners at 44 kg, refrigerators at 57 kg and washing machines at 31 kg, but this was because it was believed that the increased sizes of this equipment has been balanced out by the progress in

weight reduction and improved performance. The heavy metal volume contained in each part was established according to the study [6]. The foaming agent, CFC-11, for thermal insulators of refrigerators has been replaced gradually by HCFC and hydrocarbon since 1994, and CFC-11 was not used on those manufactured after 1996. The switch-over of refrigerator refrigerants to HCFC has been implemented since 1993, and the switch-over was completed by the end of 1995 [15]. Natural refrigerants, such as isobutene, were introduced in 1994, and over 80 percent of refrigerators were using natural refrigerants by 2001. For instance, Matsushita Electric achieved non-fluorocarbon use for refrigerators over 300 L at the end of 2003, which make up more than 95 percent of their sales [16].

The types of refrigerant in this study were established based on the literature [17] and refrigerator foaming agent was based on document [18]. It was established that isobutene has been used in earnest since 2000 as a refrigerant in refrigerators, and used fully since 2002. It was established that the air conditioner refrigerant used was completely changed to R410a by 2003. R410 is a 50/50 mixture of CH_2F_2 and CHF_2CF_3 , whose global warming potentials are 550 and 3400, respectively. It was assumed that refrigerator foaming agent for thermal insulators used would be completely changed to cyclopentane in 2006. The enclosed capacity for the refrigerant for air conditioners, and those of refrigerant for refrigerators and foaming agents of thermal insulators are changing with age. As such, the performance and volume of refrigerants for 687 units of air conditioners recycled in 2004 have been set up as seen in Table 2 from the manufacturing year data. The refrigerant amount on per

Table 2: Amount of Refrigerant of air conditioner for each year of manufacture

Period	Refrigerant rate [g/kW]	Capacity [kW]
1970–1980	833	0.98
1981–1985	776	1.14
1986–1990	729	1.17
1991–1995	590	1.25
1996–2000	527	1.17
2001–2020	438	1.17

Table 1: Material composition and weight of household appliances for each year of manufacture

Product	Period	Steel	Copper	Aluminum	Plastic	Glass	Others	Reference No.
TV	1970–1979	9%	2%	1%	0%	35%	53%	[11]
	1980–1989	9%	2%	1%	10%	46%	33%	[12]
	1990–1999	12%	3%	1%	26%	53%	5%	[12]
	2000–2010	9%	3%	1%	15%	65%	7%	[13]
Air conditioner	1970–1989	53%	19%	9%	14%	–	4%	[12]
	1990–1999	49%	18%	8%	14%	–	11%	[12]
	2000–2010	45%	16%	11%	16%	–	12%	[14]
Refrigerator	1970–1989	59%	2%	4%	30%	–	4%	[12]
	1990–1999	49%	4%	1%	43%	–	3%	[12]
	2000–2010	48%	2%	1%	42%	–	7%	[14]
Washing Machine	1970–1989	52%	3%	2%	37%	–	6%	[12]
	1990–1999	52%	2%	4%	33%	–	9%	[12]
	2000–2010	52%	4%	2%	33%	–	9%	[14]

Table 3: Amount of Refrigerant and foaming agent of refrigerator for each year of manufacture

Period	Refrigerant rate [g/L]	Foaming agent rate [g/L]	Capacity [L]
1970–1980	0.91	3.80	159
1981–1985	0.71	3.66	200
1986–1990	0.75	3.53	245
1991–1995	0.60	2.04	300
1996–2000	0.54	1.64	315
2001–2020	0.44	1.21	320

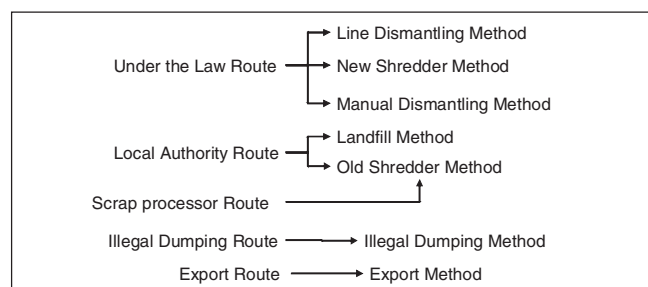
Table 4: Residual percentage of refrigerant and foaming agent for refrigerator and air conditioner

	Type of refrigerant or foaming agent	Residual percentage
Refrigerator		
Refrigerant	All	81%
Foaming agent	CFC-11	74%
	HCFC-141b	24%
	Cyclopentane	100%
Air conditioner		
Refrigerant	All	87%

kW capacity basis has been reduced compared to earlier years. The capacity and volume of refrigerants for 1,064 refrigerator units have also been set up in Table 3 from the manufacturing year data [19]. These amounts of refrigerant used per unit of power capacity have been reduced too. Refrigerants and foaming agent fluorocarbons gradually leak during the period of service. The residual percentage of refrigerant fluorocarbons has been presumed to be 87 percent with air conditioners, and 81 percent in the case of refrigerators [20]. The residual percentage of CFC-11 in thermal insulators has been presumed to be 74 percent, and the residual percentage of HCFC-141b has been presumed to be 24 percent [20]. As the data for the residual percentage of cyclopentane could not be obtained, it was presumed to be 100 percent, but since the GWP figure is low at 4, it has little effect on the outcome. Table 4 summarizes the residual percentage of refrigerant and foaming agent.

3.4 Establishing the process data

The process data was established for the following seven processing methods in this study, and the relation between 'Route' and 'Method' was shown in Fig. 4. The recovery rate of each method of each material is shown in Appendix 1.

**Fig. 4:** Relation between 'Route' and 'Method' in this study

Line Dismantling Method. This is the method primarily implemented by Group B, and processing is carried out in the updated facilities. The processing method and pre-removal of parts were developed by one of the major processing companies. The method involves workers dismantling used home appliances as they move down a conveyor. The removed parts are recovered as materials in manufacturing process. The recovery rates were established as follows: Refrigerant fluorocarbons 90 percent [19], foaming agent fluorocarbons 80 percent [21], and CRT glass 93.8 percent [22]. Singular plastics can be extracted from used home appliances, such as refrigerator food shelves, etc.

New Shredder Method. This is the method primarily implemented by Group A. Only major parts are dismantled, and the rest is shredded. After shredding, ferrous scrap is recovered by magnetic separation, while nonferrous scrap is removed using an eddy-current separator. In the survey of the major processing company, it was established that the materials recovery volume was slightly less than that of the Line Dismantling Method, and that it produced more shredded residue. However, the recovery rate of fluorocarbons and CRT glass were taken to be the same as those of the Line Dismantling Method.

Manual Dismantling Method. A greater number of parts are manually dismantled than in the Line Dismantling Method. As such, not only are ferrous and non-ferrous substances recovered, but plastic products that need more man-hours to dismantle are also recycled. For instance, with washing machines, the washing drum is dismantled, and put through a metal detector to see whether it contains any metal screws that may disturb the recycling process. Small-scale scrap processors are implementing this method, since the initial investment is small, but its share in Japan is not large. The recovery rates of fluorocarbons and CRT glass were taken to be the same as those of the Line Dismantling Method.

Old Shredder Method. This is the method that recovers valuable resources only. It is similar to the New Shredder Method, but fluorocarbons are not recovered, and glass and plastic are not recycled. This was the mainstream processing method before the Law was implemented.

Landfill Method. Landfill is carried out directly. Some local authorities implemented this method before the Law was enforced. There was no material recovery and the recovery rate of fluorocarbons was 0 percent.

Illegal Dumping Method. It was taken that dumped goods were appropriately processed after their discovery [23], and it was assumed that they were recycled using the Old Shredder Method before the enforcement of the Law, and the New Shredder Method after the enforcement of the Law. However, the refrigerant fluorocarbons recovery rate was set at 0 percent.

Export Method. Since it was deemed that disposed goods were exported abroad as reusable products, they were deemed to be beyond the boundary of the system.

3.5 Establishing the breakdown for the processing methods

The value [24] estimated from the trade statistics was used for the export volume for home appliances, but the export rate of 1995 was used for the period before 1994, and the export rate of 2000 was used for the period after 2001. It was assumed that 10 percent of second-hand home appliances are taken abroad for such users as presents that do not show up in the statistics, aside from commercial exports.

For the illegal dumping volume, the statistics [25] of 2000 was used for the period before the enforcement of the Law. There is dumping data from 2001 to 2003, so the statistics were used for each of these years. The statistics for 2003 were used after 2004. However, since the number of local authorities from which the questionnaire was collected differed by year in these statistics, the figure for illegal dumping for the whole nation was adjusted based on the population ratio. Although the volume for illegal dumping has slightly increased after enforcement of the Law, mainly for TVs that are easy to carry, the increase is not substantial. It was assumed that illegally dumped home appliances were processed by the Old Shredder Method by local authorities before the enforcement of the Law, and by the Line Dismantling Method after the enforcement of the Law. It was assumed that refrigerant fluorocarbons of refrigerators and air conditioners were discharged to the atmosphere.

With regards to composition ratios for other methods before enforcement of the Law, the rest of the units were divided into the Old Shredder Method and the Landfill Method, and the ratio between the two Methods was referred to the government report [26]. Since the refrigerant fluorocarbons recovery business began in 1993 [15], the Old Shredder Method was allocated to the New Shredder Method so that it could match with the reported volume of recovery. Meanwhile, after the enforcement of the Law, units were separated into the New Shredder Method, the Line Dismantling Method, and the Manual Dismantling Method from the processors' market share that were established by the processing performance presented on the Website or in the pamphlet of each plant. It was also presumed that the shares were constant after 2004.

Since it became mandatory to recover foaming agent fluorocarbons after 2004, it was presumed that the total volume is recovered in the processing methods of the Law. It was assumed that foaming agent fluorocarbons were only recovered through the Line Dismantling Method before that time.

Regarding the Local Authority Route, Osaka Prefecture, Hakodate City, Aomori City and Nantan City are utilizing local scrap processors to recycle used home appliances. It was found in the results of the hearing in Osaka Prefecture (with the greatest population of approx. $8.8\text{E}+6$) that $3.3\text{E}+4$ units were recovered in 2004. Since fluorocarbons were also recovered, the material recovery method was categorized as the New Shredder Method.

However, even after adding the number of units handled under the Law, through exportation through local authorities, the sum does not reach the estimated number of units discharged. As such, that gap has been attributed to other

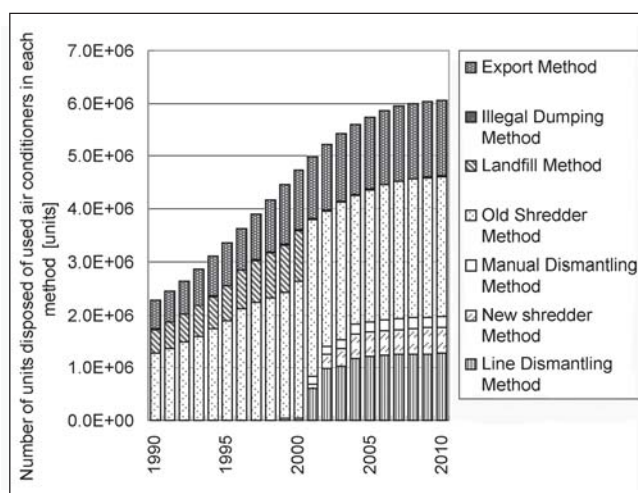


Fig. 5: Number of end-of-life air conditioners and their treatment route compositions

scrap processors' recycling and industrial waste processors. For instance, those units that were abandoned in the demolition of buildings have mixed into building waste, and those that were collected as second-hand home appliances, but were actually processed for recovering material, are not properly accounted for. These realities are uncertain, but such activities are increasing due to the increasing material prices in recent years. For this route, the Old Shredder Method was applied.

The number of end-of-life air conditioners and its treatment route compositions has been indicated using Fig. 5 as an example. This has been established according to the above-mentioned conditions. Moreover, since the error of the outcome of this calculation and the recovery volume of fluorocarbons obtained from the statistics stayed within a few percent even after the Law was enacted, the models using the fluorocarbons content and the composition ratio of technique are deemed valid.

3.6 Inventory analysis and impact assessment

JLCA-LCA-database [27] was used as background data and JEMAI-LCA Pro ver.2.0.2 Standard Dataset was used for the insufficient areas. As important process data of reproduction stage, a process data of ferrous scrap to crude steel in electric furnaces was referred the accurate data [28], and process data of landfills, pelletization of plastic, and manufacturing of copper and aluminum ingots from scrap were referred the data of previous study [8]. It was assumed that recycled materials could be substituted in the following manner; crude steel by raw crude steel, plastic by virgin plastic, copper by electrolytic copper, and aluminum by primary aluminum. It was expected that fluorocarbons were destroyed by the submerged combustion Freon decomposition system as one of the major treatment systems. The system decomposes fluorocarbons, and absorbs produced HF with alkaline water, then react it with CaCO_3 to precipitate it. The precipitation is recovered as CaF_2 and reused to generate fluorinated acids [29].

The findings of the assessments by home appliance are shown in Fig. 6 to 13. The line graphs indicate the total value for each scenario, and the bar charts indicate the composition of each element in the Project or the Baseline Scenario. It is estimated that emission reductions $4.7\text{E}+4 \text{ t CO}_2\text{e}$, subtracted the Project Scenario from the Baseline Scenario, were reduced for TVs in 2001 through recycling. The impact from recycling CRT glass is significant. An improvement of $2.3\text{E}+4 \text{ t CO}_2\text{e}$ could be anticipated by upgrading to the Ideal Scenario in 2001.

It was estimated that there was a reduction of $9.2\text{E}+5 \text{ t CO}_2\text{e}$ for air conditioners in 2001. Although the effect of the recovery for refrigerants contributed greatly, the fluorocarbons that are still discharged have a considerable impact on global warming. This is because R410a is still the typical refrigerant for air conditioners and, since there are many flows

that do not follow the processing methods of the Law, there is a lot of excess fluorocarbon discharge to the atmosphere. Hypothetically, a reduction of $3.2\text{E}+6 \text{ t CO}_2\text{e}$ could be anticipated with the Ideal Scenario in 2001.

A reduction of $2.6\text{E}+6 \text{ t CO}_2\text{e}$ emission was achieved for refrigerators in 2001. This was due to the introduction of fluorocarbon alternatives, and the recovery and processing of fluorocarbons. Although a further reduction can be anticipated through the Ideal Scenario, there will not be much difference with the Project Scenario by 2010.

It was estimated that $3.8\text{E}+4 \text{ t CO}_2\text{e}$ were reduced for washing machines in 2001. This was because it was assumed that its main constituent, iron, has been recovered previously, and the plastic recycling rate will not change significantly in the future. Improvements cannot be expected even through the Ideal Scenario.

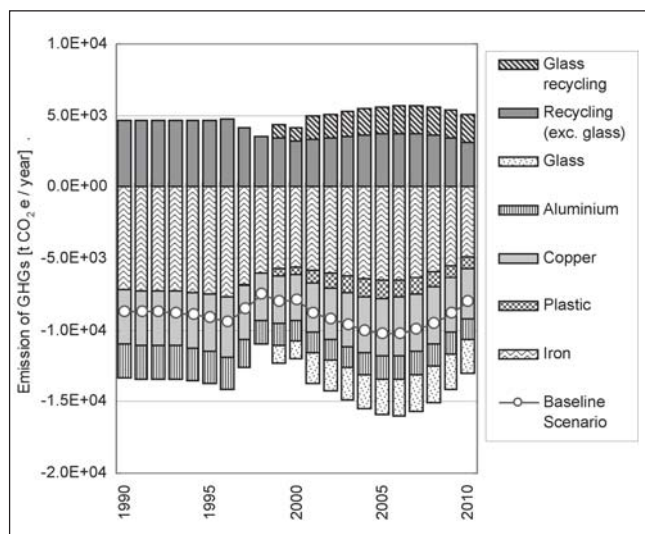


Fig. 6: GHGs emissions from end-of-life TV sets treatment with the Baseline Scenario from 1990 to 2010 in Japan

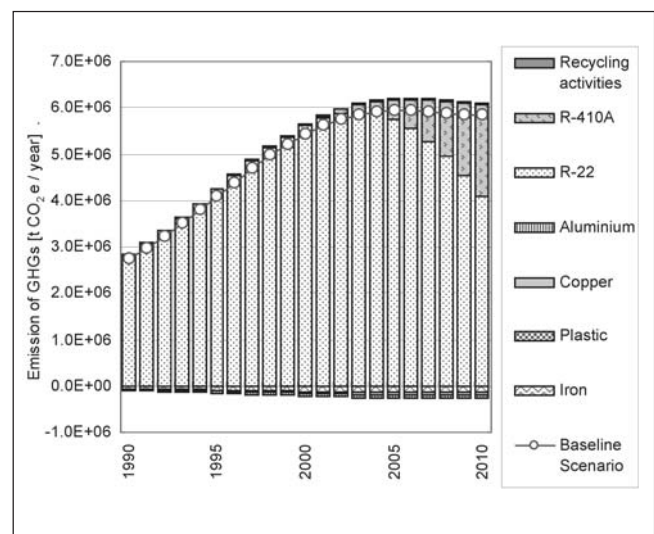


Fig. 8: GHGs emissions from end-of-life air conditioners treatment with the Baseline Scenario from 1990 to 2010 in Japan

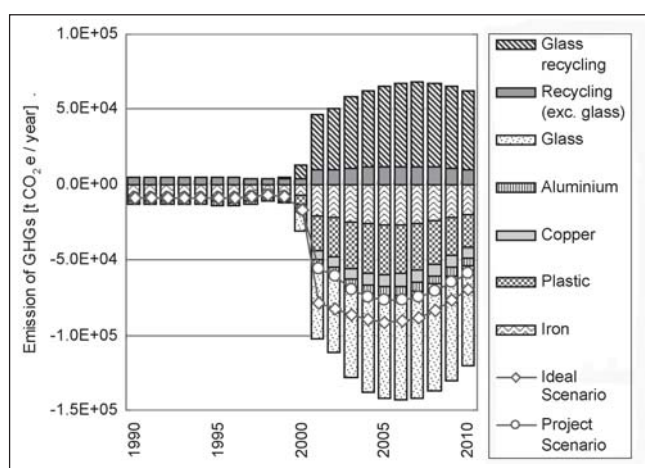


Fig. 7: GHGs emissions from end-of-life TV sets treatment with the Project and Ideal Scenario from 1990 to 2010 in Japan. The bar charts indicate the composition of each element in the Project Scenario. Note that the Y-axis is different from that in Fig. 6

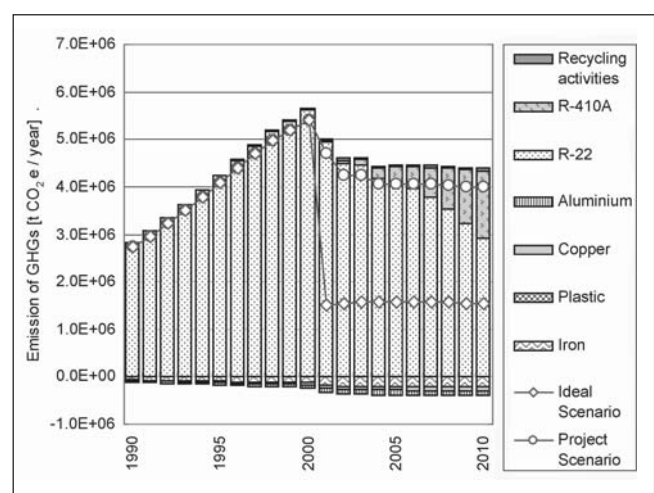


Fig. 9: GHGs emissions from end-of-life air conditioners treatment with the Project and Ideal Scenario from 1990 to 2010 in Japan. The bar charts indicate the composition of each element in the Project Scenario

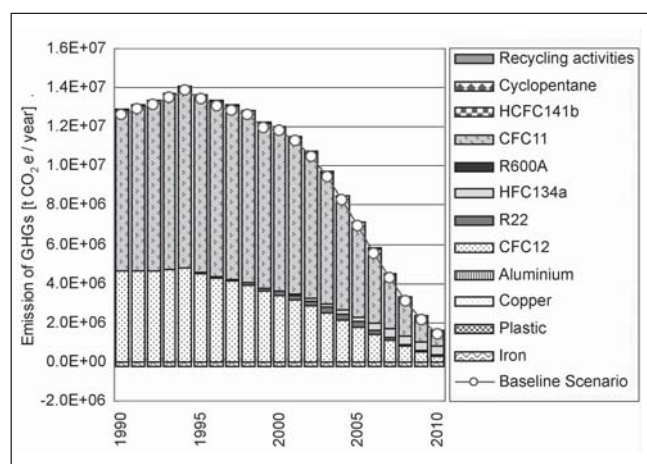


Fig. 10: GHGs emissions from end-of-life refrigerators treatment with the Baseline Scenario from 1990 to 2010 in Japan

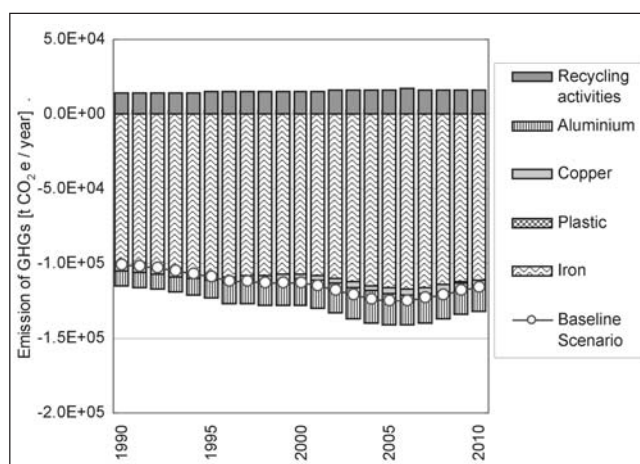


Fig. 12: GHGs emissions from end-of-life washing machine treatment with the Baseline Scenario from 1990 to 2010 in Japan

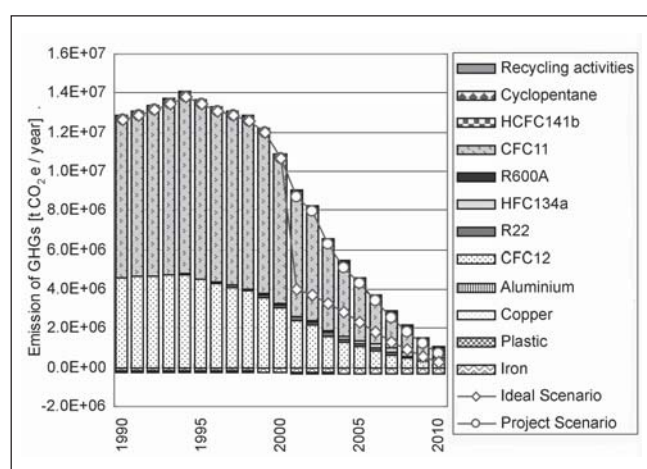


Fig. 11: GHGs emissions from end-of-life refrigerators treatment with the Project and Ideal Scenario from 1990 to 2010 in Japan. The bar charts indicate the composition of each element in the Project Scenario

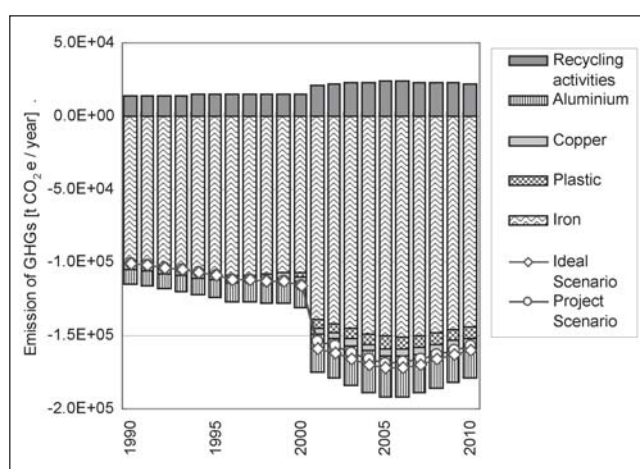


Fig. 13: GHGs emissions from end-of-life washing machine treatment with the Project and Ideal Scenario from 1990 to 2010 in Japan. The bar charts indicate the composition of each element in the Project Scenario

3.7 Sensitivity analysis

Since many assumptions were used in this study, a sensitivity analysis was carried out in order to grasp their impact. A mean value was required in this study, and the distribution of individual pieces was unnecessary, e.g. weight distribution of household appliances. In order to explicit the margin

of the error of the mean value obtained in this study, a probability density distribution was used. The variable sensitivity was analyzed and the applied probability density distribution, the maximum and the minimum of the distribution are shown in Table 5. Sensitivity analyses were carried out through the Monte Carlo method. The findings of the sen-

Table 5: Parameters for Sensitivity analysis. *T: TVs, A: Air conditioners, R: Refrigerators, W: Washing machines

Factor	Distribution profile	Fluctuation band	
		2001	2010
Quantity possessed in Japan	Triangular distribution	±1% (Mean value: *T: 7.6E+7; A: 4.5E+7; R: 4.8E+7; W: 4.3E+7 [unit])	±10% (Mean value: *T: 1.0E+8; A: 1.1E+8; R: 5.7E+7; W: 5.3E+7 [unit])
Average life time	Triangular distribution	±1%	±10%
Average weight	Rectangular distribution	±5%	±10%
Exporting rate	Rectangular distribution	±50%	±100%
Environmental burden of material production	Triangular distribution	±5%	±10%
Amount of fluorocarbons	Rectangular distribution	±10%	±10%

Table 6: Result of Sensitivity analysis

	Emission of GHGs from 2001 to 2010			Reduction of GHGs from 2001 to 2010	
	Baseline Scenario	Project Scenario	Ideal Scenario	Baseline Scenario to Project Scenario	Project Scenario to Ideal Scenario
TVs	$-1.4\text{E}+5 \pm 7.0\text{E}+4$	$-7.7\text{E}+5 \pm 1.5\text{E}+5$	$-1.2\text{E}+6 \pm 5.0\text{E}+5$	$6.3\text{E}+5 \pm 1.0\text{E}+5$	$4.0\text{E}+5 \pm 3.9\text{E}+5$
Air conditioners	$5.8\text{E}+7 \pm 2.5\text{E}+6$	$4.1\text{E}+7 \pm 1.9\text{E}+6$	$1.6\text{E}+7 \pm 9.7\text{E}+6$	$1.7\text{E}+7 \pm 6.5\text{E}+5$	$2.6\text{E}+7 \pm 9.0\text{E}+6$
Refrigerators	$6.3\text{E}+7 \pm 3.2\text{E}+6$	$4.2\text{E}+7 \pm 2.2\text{E}+6$	$2.1\text{E}+7 \pm 6.4\text{E}+6$	$2.1\text{E}+7 \pm 9.6\text{E}+5$	$2.1\text{E}+7 \pm 6.0\text{E}+6$
Washing machines	$-1.2\text{E}+6 \pm 8.7\text{E}+4$	$-1.6\text{E}+6 \pm 1.8\text{E}+5$	$-1.7\text{E}+6 \pm 1.9\text{E}+5$	$4.1\text{E}+5 \pm 1.4\text{E}+5$	$3.7\text{E}+4 \pm 7.3\text{E}+3$
Total	$1.2\text{E}+8 \pm 5.8\text{E}+6$	$8.1\text{E}+7 \pm 4.5\text{E}+6$	$3.4\text{E}+7 \pm 1.7\text{E}+7$	$3.9\text{E}+7 \pm 1.8\text{E}+6$	$4.7\text{E}+7 \pm 1.5\text{E}+7$

sitivity analysis are shown in Table 6. Though the uncertainties are large, the number of the GHGs reductions is still clear, except for the difference between the Project Scenario and the Ideal Scenario for TVs. This analysis gives authenticity to the findings described above.

4 Conclusions, Recommendations and Perspectives

The impact from recycling CRT glass is significant for TVs. An improvement of recycling method is not effective because the absolute amount of CRT TVs will rapidly decrease from 2007. Establishing a system for managing LCD/PDP TVs is desirable, although the lifetime of LCD/PDP TVs is longer than CRT.

With regard to refrigerant recovery from air conditioners, a significant decrease in GHG emissions has been recorded. However, there is still ample room for improvement. This is because R410a is still the mainstream refrigerant for air conditioners, and since there are many units that are not handled within the confines of the Law, there are a lot of fluorocarbons discharged. It will be necessary to switch to a refrigerant with a low GWP or work more on improving the recovery rate in the future.

Alternatives to fluorocarbons and recovery of fluorocarbons from refrigerators contributed greatly towards GHG reductions. Although a further reduction can be anticipated through the Ideal Scenario, there will not be much difference between that scenario and the Project Scenario by 2010. Since the discharge percentage of refrigerators that use natural refrigerants will increase, it shows that there is no great impact even if the units are handled through an illegal process that recovers valuable metals only.

The improvement for washing machines was low because it was assumed that its main constituent, iron, has been previously recycled, and that the plastic recycling rate will not change significantly in the future. Significant improvements cannot be expected even through the Ideal Scenario. This is not a problem caused by the processing route, but an improvement in the recycling technology itself is required. Since there is now a movement to recycle plastics, a technology that can utilize such unused resources will be required.

This study was carried out on four home appliances, and it was found that the Home Appliance Recycling Law has brought significant GHG reductions, totaling $3.9\text{E}+7$ t CO₂e

from 2001 to 2010. There is also room to reduce emissions a further $4.7\text{E}+7$ t CO₂e through improved processing methods. The impact on GHG emissions by fluorocarbons of air conditioners and refrigerators is the greatest. Adequate measures are particularly required for air conditioners that may continue to discharge GHGs in the future. As it is possible to quantify the environmental benefit effect in this way and clarify future tasks, the LCA method can be a useful tool in policy evaluation and policy planning.

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Appendix 1: Recovery rate in each Method at end-of-life household appliance recycling plants

Product	Method	Steel	Copper	Aluminum	Plastic	Glass	Fluorocarbons
TV	Line Dismantling	94%	92%	71%	90%	94%	–
	New shredder	25%	62%	23%	90%	94%	–
	Manual Dismantling	91%	98%	71%	90%	94%	–
	Old Shredder	25%	62%	23%	0%	0%	–
Air conditioner	Line Dismantling	98%	98%	98%	12%	–	90%
	New shredder	84%	75%	72%	12%	–	90%
	Manual Dismantling	98%	98%	98%	12%	–	90%
	Old Shredder	84%	75%	72%	0%	–	0%
Refrigerator	Line Dismantling	98%	90%	92%	4%	–	90%
	New shredder	98%	90%	86%	4%	–	90%
	Manual Dismantling	98%	90%	92%	4%	–	90%
	Old Shredder	98%	90%	86%	0%	–	0%
Washing Machine	Line Dismantling	98%	77%	83%	22%	–	–
	New shredder	98%	76%	76%	22%	–	–
	Manual Dismantling	98%	77%	83%	65%	–	–
	Old Shredder	98%	76%	76%	0%	–	–